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1 PURPOSE AND CHALLENGE OF MONITORING CRITICAL INFRASTRUCTURE

1.1 Motivation and challenge

‘Horizon Europe’ is one the European Union’s key funding programs for research and innovation [1]. One of the five mission areas of this program is the adaptation to climate change. Climate change can lead to extreme weather events or even natural disasters, with corresponding consequences for the people affected. The impact of such events on relevant infrastructures such as energy supply, communication and transport can quickly become critical, as disruptions to these infrastructures can have a major impact on daily life. To be able to restore the functionality of critical systems promptly after an incident, it is important to quickly gain an overview of the overall situation. Reliable monitoring of such critical infrastructures would therefore be of interest to many stakeholders, from state institutions such as transport ministries and civil protection to energy suppliers, telecommunications companies, railway companies and logistics companies. In addition to the European market, the worldwide use of such services is also promising. As part of the "Horizon Europe" program, the project “*Instantaneous Infrastructure Monitoring by Earth Observation*” (IIMEO) aims to develop and demonstrate key technologies for the global monitoring of critical infrastructures from space in near real time.

Several methods are currently used to monitor critical infrastructure, such as sensor-based monitoring of certain sections (e.g. for railway tracks or bridges), local monitoring with cameras (mainly for buildings), airborne monitoring or manual inspection of routes. Although these methods are feasible, they lack the ability to monitor infrastructures continuously and on a large scale. Furthermore, it is not always possible to quickly check infrastructures after or even during extreme weather events, such as storms or flooding.

Satellites have been proven to be useful to fulfil such requirements, since they can operate independently from the earth’s atmospheric interferences. Also, such kind of infrastructure monitoring seems already technical feasible with existing technologies. So, the main question is: **Why aren’t such earth observation (EO) services for infrastructure monitoring already available on the market?**

Generally, earth observation satellites offer the possibility of regular monitoring of critical infrastructure from space. However, current spaceborne systems are not able to instantaneously detect whether infrastructure has been damaged in case of extreme weather events or natural disasters. Main reasons are long response times or low spatial and temporal resolution. The response time depends largely on when a satellite returns to the affected area, how long it takes to transmit all acquired data to the ground station and how long it takes to analyse the data before a result is available. Finally, due to the resulting operational costs such installations are currently uneconomical and not operable under commercial terms and conditions. Therewith, the number of satellites in constellation and data downlink being the key bottleneck in the system.

To summarise, there is currently a high demand for an infrastructure monitoring solution meeting the following main requirements:

- **Near-real time monitoring** of large-scale infrastructures (railways, pipelines, etc.)
- **Monitoring independent from current local weather conditions** (cloudy, stormy etc.)
- **Economically sustainable monitoring,** scalable at reasonable operational efforts

1.2 IIMEO solutions to meet the challenge

The aim of IIMEO is to meet this challenge and to develop suitable solutions that enable **timely** and **reliable** monitoring of critical infrastructure at any time. To achieve this goal, the following requirements must be met: *The time span between starting a monitoring task and receiving the monitoring results shall be maximum of one hour long and the monitoring shall be possible regardless of the time of day and weather conditions.*

To fulfil these requirements and develop an affordable and commercially vialbe solution, IIMEO faces the following technical challenges:

- Designing and prototyping a **novel on-board data processor**, which is capable to process/analyse data on-site in the satellite, to dramatically **reduce data downlink** and to shorten time needed for instantaneous infrastructure monitoring service
- Developing **advanced SAR and VIS data analysis algorithms**, operable on-board of a potential LEO satellite constellation

IIMEO pursues the following concept to fulfil the requirements: Infrastructure monitoring with a revisit time of less than one hour is a prime example of satellite-based systems regarding the principles of "NewSpace" [2] with a constellation of a sufficient number of small satellites in low earth orbit (LEO, 500 to 900 kilometers altitude) that together achieve the desired coverage and response times. To avoid transmission bottlenecks, most of the calculations are carried out on-board using the data collected immediately beforehand. This includes AI-supported detection of changes and anomalies in the observed infrastructures as well as data compression before transmission to the ground. A novel sensor configuration, consisting of a 35 GHz SAR sensor in combination with high-resolution optical cameras, will be used to provide a weather and time-of-day independent monitoring service with a suitable spatial resolution for the on-board computations.

The main objective of the project is to select and integrate innovative sensor and processing technologies into the payload (called on-board platform) that enable time-critical calculations to be processed already on-board. To achieve the most comprehensive monitoring possible, two different sensor types are used: a Ka-band sensor for high-resolution SAR images and high-resolution RGB cameras that capture visible light (VIS cameras). Both complement each other to provide robust, weather- and time-independent imaging. They are complemented by a powerful on-board processor that enables the use of state-of-the-art, AI-supported data processing for change and anomaly detection on the observed infrastructures. The on-board platform is designed with space applications in mind but will initially -in the scope of the IIMEO project- be integrated in an airborne technology demonstrator to verify the suitability of the technical solution before sending it into space as satellite payload in a follow-up mission.

Further project activities are related to the design of the complementary on-ground platform and a suitable user interface, which shall be customisable for different use cases and monitoring services. The on-board and on-ground platforms together with the user interface build up the entire processing chain for the infrastructure monitoring.

Once the development phase has been completed, all relevant key technologies will initially be integrated in an **airborne technology demonstrator** to verify the suitability of the technical solution before sending it into space as satellite payload. The goal of the flight campaign planned for the final project year is to demonstrate the end-to-end prototype downstream service, including on-board data processing. The automated detection of obstacles on railway tracks is to serve as an example application. The national company for the management of railway infrastructure in Serbia was won as a cooperation partner and pilot user. Slobodan Rosić, Serbian Railway Infrastructure (SRI) Risk Manager, points out: "A satellite-based automatic monitoring system makes it possible to collect high-quality information about the condition of the infrastructure in real time without having to interrupt regular traffic and without the need for personnel on site."

The automatic detection of obstacles on railway tracks will serve as an example application. A follow-up demonstrator mission in 2026/27 is envisaged to showcase the monitoring of railways from space on a global scale.

1.3 Classification of Information

This document has been reviewed by the Security Advisory Board of the IIMEO project against the criteria set out in [3]. In particular, the criteria listed in chapter 4.3 (Critical infrastructure and utilities research) were considered. All information in this document can be published with the classification “Public” for the following reasons:

- The document describes a hypothetical construct that is yet to be proven through a demonstrator.
- The document does not include highly technical details.
- The technology described in the document is public information and can be subsumed from freely available sources.

1.4 Document structure

The following sections will provide more details on the elements of the IIMEO concept:

- **Section 2** describes the overall architecture of the IIMEO system.
- **Section 3** provides a brief overview of the envisaged application scenario, that will be demonstrated for the planned flight campaign in 2025.

2 HOW WILL IIMEO MEET THE CHALLENGE

As outlined in the previous section, the IIMEO consortium considers a “NewSpace” approach as the most suitable solution to meet the set objectives. The term "NewSpace" [2] describes concepts and developments in cost-effective space technologies that enable the expanded commercial utilisation of space. The low costs of such a SmallSat are achieved on the one hand by its limited weight and on the other hand by a high amount of built-in 'Commercial off-the-shelf' (COTS) components. The higher number of satellites also enables cost-effective mass production. All these aspects finally lead to a faster return of invest.

For the IIMEO project, the use of a constellation of SmallSats in low earth orbit (LEO) is promising for the following reasons: A constellation of a sufficient number of satellites ensures the desired coverage and required response times below one hour. Furthermore, the LEO with 500 to 900 kilometers altitude allows SAR and VIS data to be recorded at a sufficiently high resolution for the subsequent detection of infrastructure disruptions. As calculated in [4], a satellite constellation of at least 24 satellites on 3 or 4 orbital planes is required for IIMEO purposes. Keeping this number and a targeted return of investment in mind, this is a use case of SmallSats in the mass range below 200kg, where the investment costs per satellite is expected to be below EUR 10 million (in opposite to bigger satellites such as ENVISAT, SAR-Lupe or EnMAP). Candidates for such a SmallSat have already been listed in [4].

As stated in the previous section, the main activity of the IIMEO project is to design and integrate a corresponding payload, consisting of innovative sensor and processing technologies, which can perform the time-critical monitoring tasks on-board. To achieve the most comprehensive monitoring possible, two different sensor types are used: a Ka-band sensor for high-resolution SAR images and high-resolution RGB cameras that capture visible light (VIS cameras), together providing robust, weather- and time-independent imaging. Besides the sensors, the payload also includes a powerful on-board processor to perform AI-supported data processing for change and anomaly detection on the observed infrastructures. The system is completed with an on-ground platform and a suitable user interface to build up the entire processing chain from end-user to on-board platform. Figure 2-1 shows the overall architecture of the IIMEO system with the main element ‘On-board Platform’ and the complementary ‘On-ground platform’ and user service elements.

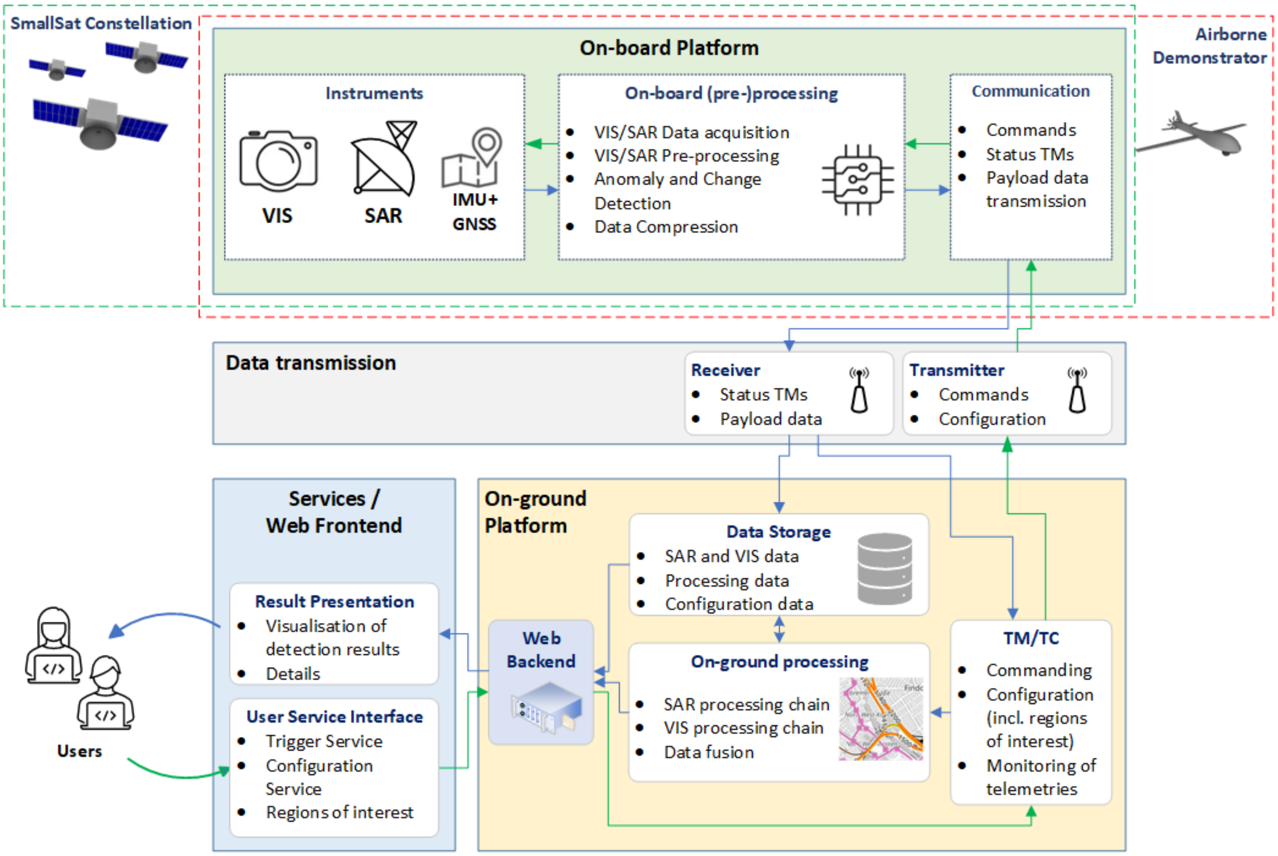

Figure 2-1 IIMEO overall system architecture

As can be seen in Figure 2-1, the on-board platform is designed with space applications in mind but will initially be integrated in an airborne technology demonstrator to verify the suitability of the technical solution before sending it into space as satellite payload in a follow-up mission.

The individual elements of the IIMEO system will be described further on in the following subsections, while the application scenario for the final demonstration flight campaign is described later in section 3.

2.1 On-Board Processing Platform

As discussed above, IIMEO uses a demonstration plane instead of actual satellites to avoid cost and risk of deploying the sensing and processing payload on actual satellites, which would be out of reach if the first prototype turned out to be imperfect in some way – which it likely will.

The platform which is used instead is OHB's "Condor" airplane, which is a motorized sailplane based on the Stemme S10. It has 23 m wingspan and can bear two sensor pods, one per wing weighing up to 60 kg each. The plane's maximum speed is 270 km/h, however, with sensing equipment attached, it is usually operated at around 120 km/h. Figure 2-2 is a picture of that plane.

Figure 2-2: IIMEO flight platform used in lieu of a satellite to develop and demonstrate infrastructure monitoring with on-board processing. The image is taken from [5] and shows the plane with only the pod below the left wing attached.

The platform carries quite a bit of processing and sensing equipment both in the fuselage as well as in two pods to be mounted below its wings. Aside from the nadir- and obliquely looking cameras and the SAR, there are acquisition computers querying the cameras and encoding their outputs as well as a separate SAR acquisition computer responsible for the image formation from raw SAR data. The process is distributed across the plane as follows, see also Figure 2-4:

The cockpit will contain the on-board processing unit which is used to run the bulk of the processing to discover changes of SAR imagery and anomalies in VIS images of railway tracks, both indicating defects. It also contains the communication link to ground. The left wing-pod contains the nadir-looking VIS camera, a data acquisition computer to store and forward the camera's images as well as to acquire the wing-pod's localization and orientation from an IMU+GNSS combination, which is also contained in this pod. The right wing-pod contains the SAR and the oblique-looking camera pointed into the same direction as the SAR. As mentioned above, both SAR and VIS camera are connected to their own data acquisition computers to both store and forward the acquired data. The right wing-pod also contains its own IMU+GNSS sensor unit to provide motion, attitude and localization estimates required for SAR image processing and formation. It also includes a processing hardware unit for on-board real-time data synchronization and SAR processing. The current status of this right wing-pod is presented in Figure 2-3.

Figure 2-3: Current status of the right wing-pod containing the oblique-looking Ka-band FMCW SAR sensor with slotted wave guides antennas and SAR processing hardware unit. On the right side the integrated PhaseOne VIS camera is visible.

Since the wings and the mounting on the body of the plane are not perfectly rigid, their orientation with respect to each other will vary a bit during a flight.

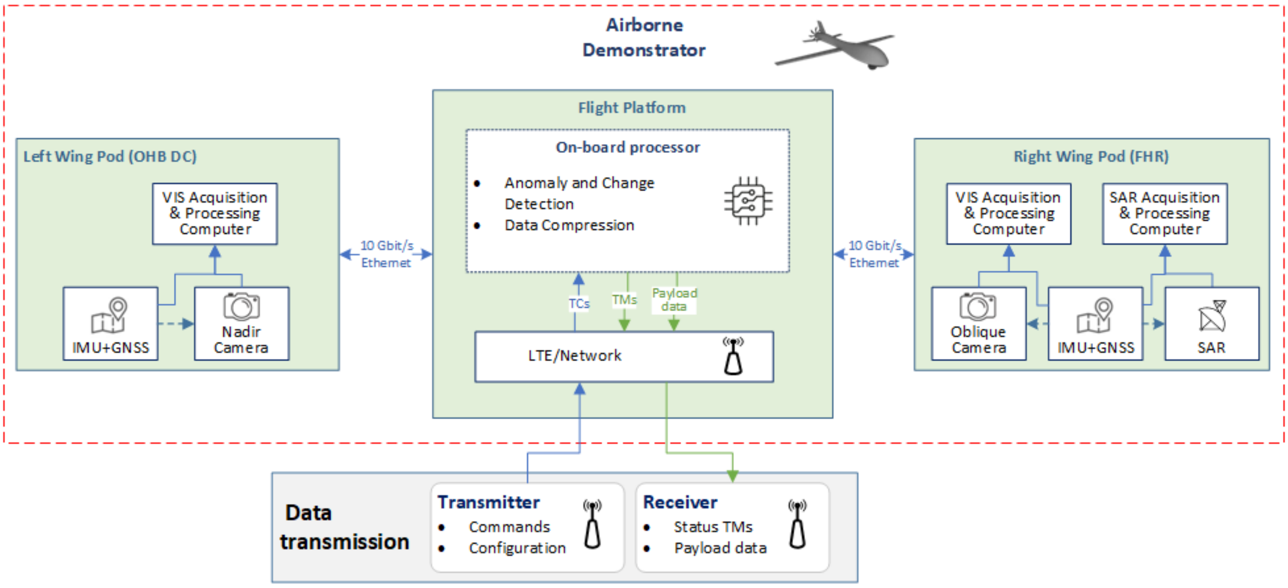

Figure 2-4: Distribution schema of sensing and processing hardware on the demonstrator plane.

To coordinate the execution of various processes performing data acquisition, all the computers aboard the plane run ROS2, the “Robot Operating System” [6]. ROS2 provides infrastructure and tools for most of the cross-cutting concerns arising when operating a platform like this, e.g. logging, communication between individual processes as well as the management of their lifecycle, i.e. launching and stopping them. In particular, the imagery acquired using the VIS acquisition computers and formed by the SAR acquisition computer needs to be communicated to the On-Board Processor. To use ROS2 to distribute those messages, the plane has two 10-Gbit/s-Ethernet links, connecting both wing pods to the central on-board processing unit in the fuselage.

A reduced overview of the processing carried out either by the computing hardware on-board or by the on-ground platform (see section 2.2) is given in Figure 2-5. This starts with the acquisition of inputs prior to processing. Aside from the acquisition of sensor data, i.e. SAR data, VIS images and platform motion and localization estimates from the IMU+GNSS, there is static data denoted as region of interest (ROI) at the top of Figure 2-5. These are the regions of interest (ROI), which are geographic areas surrounding the relevant infrastructure, i.e. railway tracks.

To generate images and compute railway defects only in areas where railways possibly can occur, we use maps to identify regions of interest prior to the actual flights. Thus, this happens before the actual operation independently from the rest of the processing steps and is repeated only upon changes in the map data. One of the maps we use for this is OpenRailwayMap [7], where railway tracks are represented using piecewise-linear curves, which we use in turn to compute polygons marking the regions were railway tracks could possibly appear and, conversely, where we do not have to look for railway tracks, namely outside those polygons.

While acquiring the input raw data, the actual data processing branches into two more or less independent processing chains, one processing SAR data and the other processing VIS images. Both branches will finally produce a product indicating defects of railways tracks. The SAR chain indicated in section 2.1.1 will accomplish this by forming a geo-referenced image using the RADAR data, which is then compared to reference SAR image acquired when the railway tracks under monitoring were in a fault-free state. The actual SAR illumination mode it further described in section 2.1.2. Changes of the newly acquired SAR image with respect to the reference then indicate defects. The VIS starts out differently, because in contrast to the radar, the cameras directly put out images directly, so no “image formation” step is required here. However, there is no geo-reference, while in the SAR case it can be designed to be a by-product of SAR image formation. Thus, the first processing step for VIS images is the geo-referencing itself. This step does not change the image itself, but it annotates the image with the world-coordinates of the four image vertices. Using these and assuming an approximately flat ground surface, the locations of the physical points on ground corresponding to the image pixels and conversely the image coordinates of ground points in the camera’s field of view can be approximately computed. This is used to compute the regions of interest in each image from the static ROI data.

In case the ground in the camera’s field of view is not sufficiently flat, the image is also ortho-rectified. This process is similar to geo-referencing, but it also takes the ground’s relief into account. This results in a more accurate mapping of physical ground coordinates to image coordinates. At the end of ortho-rectification, the image is re-sampled to a grid of pixels which are equally distributed in the horizontal ground coordinates. However, some of those may be occluded by high relief between the camera and the ground pixel in question, so in an ortho-rectified image, some pixels will likely end up without a corresponding image pixel. So, in contrast to geo-referencing, the image is not only annotated with the coordinates but might look a little different from the original image after resampling.

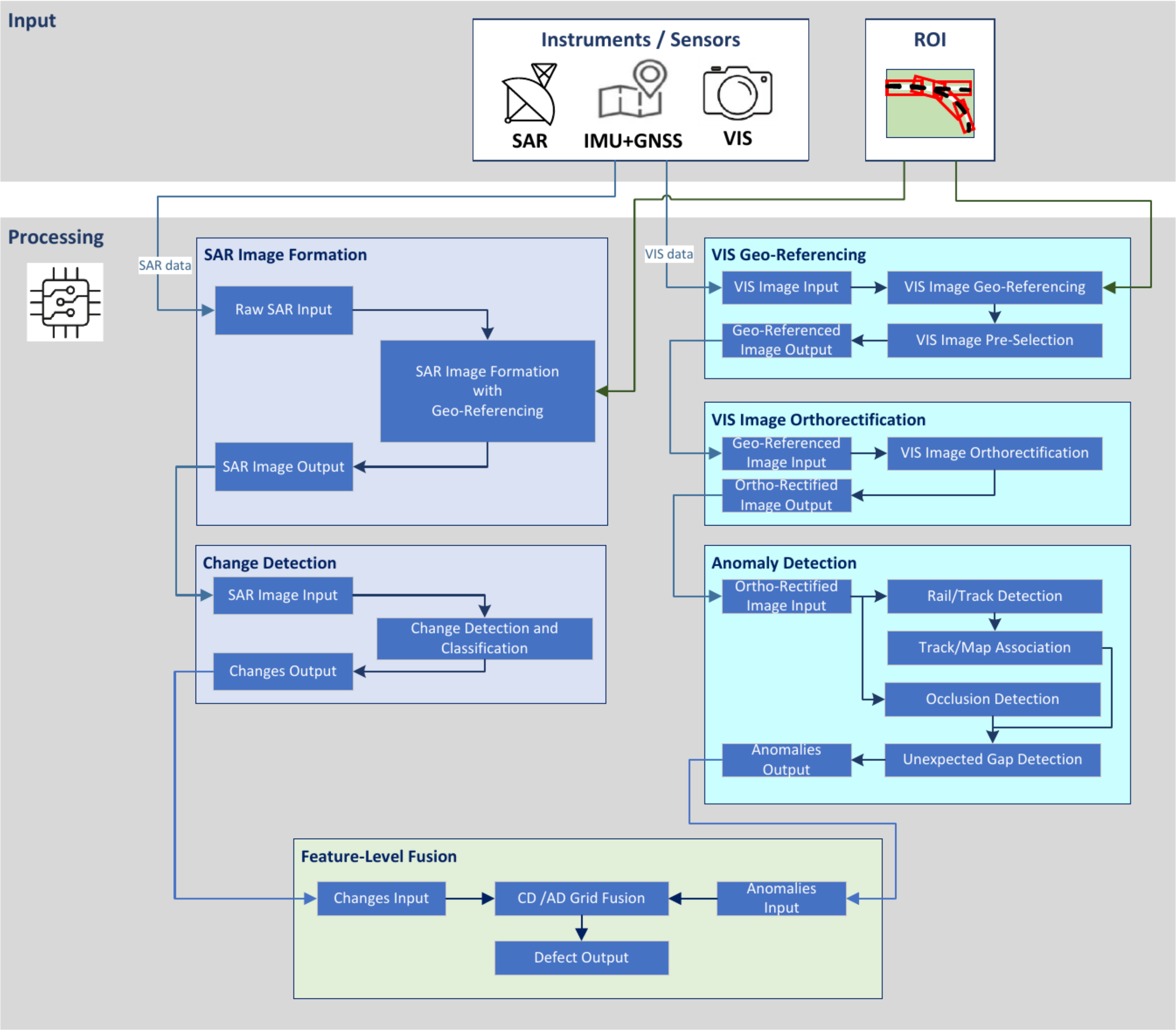

Figure 2-5: Reduced view of the processing graph from SAR/VIS sensors to rail track defect outputs.

The geo-referenced or ortho-rectified image is finally passed to the anomaly detection step. This step uses static map data, such as data from the OpenRailwayMap [7], to compute where the pixels belonging to the railway track should appear in the image. These are then compared to the measured pixels. To this end, the measured images are passed to a classifier which considers pixels and their neighbourhood and labels the pixels as “track pixels” or “no track pixels”. If no rail appears where it is supposed to appear according to the map data, the corresponding location is marked as an anomaly indicating somehow defective parts of the railway track.

At the end of the branches for VIS images and SAR data, there are two data products which indicate defective parts of railway tracks: the outputs of change detection and anomaly detection. To compute a data product based on both SAR and VIS data, the two processing branches are joined by the Feature-Level Fusion. This step, shown at the bottom of Figure 2-5, collects evidence of railway track defects from both change detection and anomaly detection and computes the most likely defect labels given the evidence of both data sources.

2.1.1 Real-time on-board SAR processing

One of the key elements in the IIMEO project for detecting relevant changes in the target area in near real-time regardless of the current weather or daylight situation and simultaneously reducing the amount of data to be transmitted to a ground station is near real-time on-board SAR focusing and processing of the raw SAR data acquired by the SAR sensor. This means that the real-time on-board SAR processor can be regarded as one of the major starting points for the subsequent on-board processing steps, as indicated in Figure 2-6, which shows the proposed real-time SAR on-board processing framework for IIMEO. The SAR image data, processed and georeferenced in near real-time, form the input for the subsequent change detection of the target area of interest.

Considering the derived infrastructure areas of particular interest (ROIs), the developed SAR algorithms must allow highly parallel and highly efficient on-board processing of the SAR raw data with limited hardware-resources. As an output of this process chain, SAR image sequences of the area of interest are continuously generated and streamed to the on-board change detection process.

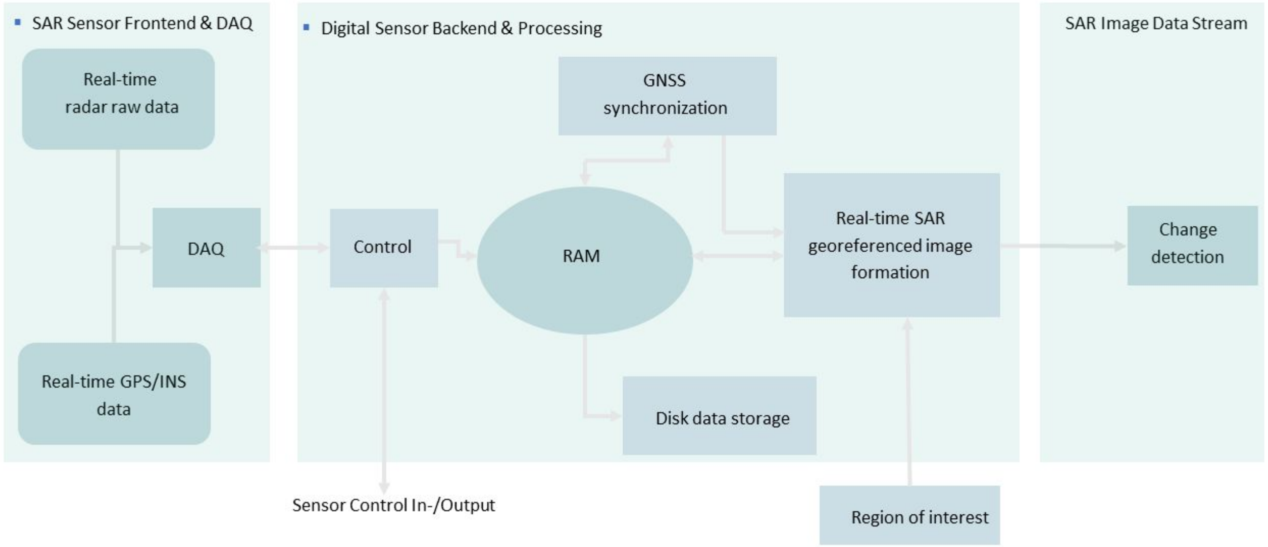

Figure 2-6: Proposed real-time SAR on-board processing framework.

2.1.2 SAR illumination mode

In the IIMEO project, a so-called SAR stripmap mode is being evaluated as the illumination mode of the SAR sensor constellation. In this mode, the carrier platform moves along a fixed orbit or, in the airborne case, on a linear flight trajectory while the SAR sensor illuminates the earth's surface at a predefined, fixed depression angle and continuously stores the received radar echoes, as outlined in Figure 2-7. The SAR sensors' antennas are usually fixed in this illumination mode and no active beamforming is applied.

The footprint of the SAR sensor sweeps across the target area – railway tracks in the IIMEO context - at a constant speed relative to the carrier platform. The depth of the footprint in range dimension is determined by the 3dB aperture angle of the SAR antenna in elevation. The instantaneous lateral width of the footprint is defined by the 3 dB aperture angle of the SAR antenna in azimuth.

Each target area is covered with a complete footprint, i.e., the exposure time is proportional to the size of the azimuthal section. While the range resolution in this mode is determined by the radar's RF bandwidth, the azimuthal resolution is limited by the physical antenna length in azimuth. Stripmap SAR uses a periodic sequence of pulses to obtain a continuously growing mapped strip of a SAR image. To remain unambiguous, it must be ensured that the pulse repetition frequency (PRF) applied is higher than the expected Doppler bandwidth of the received signal.

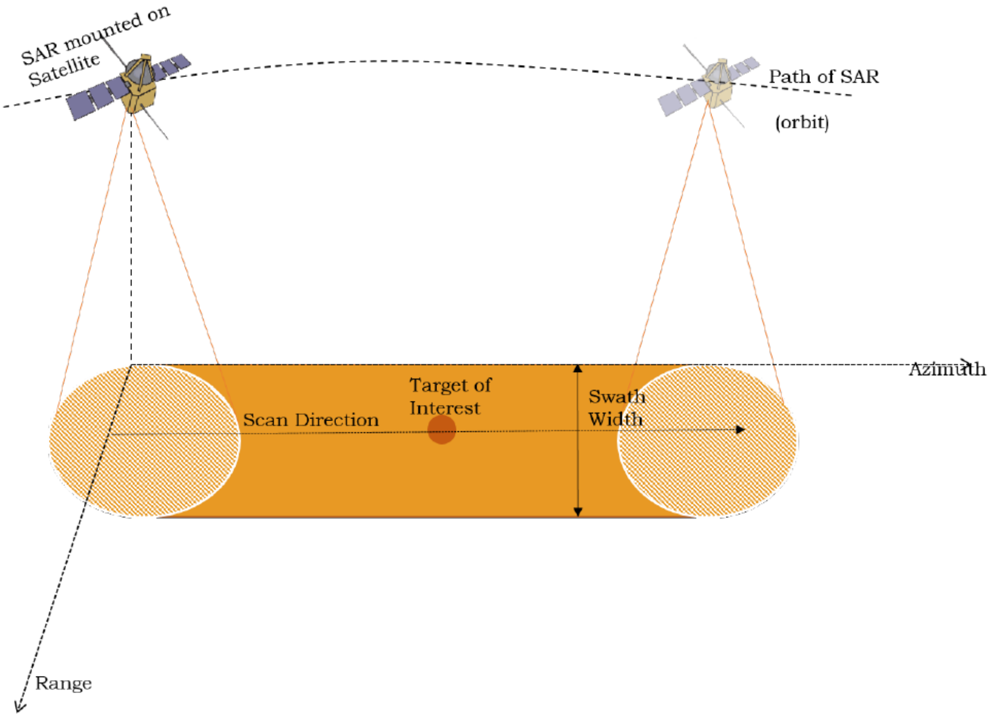

Figure 2-7: Stripmap SAR illumination mode.

2.2 On-Ground Platform

Within the scope of the project, the data processing, storage and service in the ground segment will be implemented as a cloud-based prototype platform, further on called “on-ground platform”, using custom or commercial/open-source tools for data distribution and service provision. Service and processing design for the off-board segment will reflect advances of the “Generic Infrastructure Monitoring Platform” prototype, a service platform developed within the CityCLIM Horizon 2020 project [8] which is an ideal candidate for future commercialization of infrastructure monitoring services. This cloud-based platform is intended to provide storage engines for generic data processing workflows, interfaces for receiving and providing data upon request as well as billing and account systems. The pilot service, railway monitoring, will be accessible to the pilot user via a web interface during demonstration. The platform is intended to host multiple services using different data sources, and to provide direct access to data products via EO data services.

The on-ground platform provides resources for the supplementary processing and storage of the data received from the space system that is from the airborne demonstrator. Which of the processing steps described in section 2.1 and displayed in Figure 2-5 will run on-ground and which ones on-board has not been finally determined yet. Some of the steps, e.g. those immediately following data acquisition such as SAR image formation, must be carried out on-board because their results are a precondition to do any on-board computations at all. Beyond this, it is desirable to move as much processing as possible to the on-board side to avoid communication delays which would make meeting deadline for the results difficult. On the other hand, there are much more computational resources available on ground than there are on-board, such that computations processing the data at greater resolution are more affordable when executed on the platform prototype. Thus, the compromise currently planned is as follows: The low-resolution but functional version of the processing chain of Figure 2-5 will run on-board, delivering results in acceptable time. Once that happened and capacity is available, intermediate results will also be transferred from the on-board platform to enable the

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re-computation of some of the processing steps yielding results at an increased resolution for further inspection.

The prototype platform also includes components that implement the interfaces to the User Services/Web Frontend on one side and to the on-board platform on the other side (see Figure 2-1). Figure 2-8 presents a more detailed view of the on-ground processing platform with the following elements included:

- **Web Backend**: This element provides the interface to the User Services and the corresponding frontend. It includes data services (such as GIS services, databases, provision of processing results etc.), the service management (implementing the definition of tasks and respective configurations to be sent to the space system resp. airborne demonstrator) and middleware functionality.
- The **TM/TC element** receives tasks and configuration data from the Web Backend service management and translates them to corresponding telecommands (TCs) that will be send to the on-board platform afterwards. It also receives and processes telemetries (TMs) sent from the on-board platform, such as status telemetries of the payload units and notifications that payload data was sent. In the latter case, the TM/TC element triggers the respective on-ground processing chains to start their tasks. The communication applies a mission-specific tailoring of the standardized PUS service types and additional service types, e.g. for monitoring and control of the payload units (see [9] for details).
  For the envisaged SmallSat, the set of TCs and TMs would include commands and telemetries for the satellite platform as well as for the satellite payload. In case of the airborne demonstrator, only the relevant payload TCs and TMs will be implemented.
- The **Data Acquisition Unit** receives the payload data from the on-board platform and writes it to the **Data storage**. The **Data Storage** in turn provides this incoming data to the processing chains. It is also used to store intermediate processing results from the processing chains. Moreover, it provides an interface to the Web Backend to finally forward the processing results to the user frontend.
- The **SAR and VIS processing chains** perform image processing and analysis tasks to finally detect changes or anomalies on the selected railway tracks. They read the input data from the Data Storage device and additional data, such as region of interests, from the underlying messaging system. They also store intermediate processing data and result data on the Data Storage. The steps of the processing chains are outlined in Figure 2-5. The processing chains have a modular structure, with individual containers for the respective processing steps, a message broker software for inter-module communication and a common storage device for data exchange. This modular structure provides easier maintainability and high portability of the individual processing steps. It also eases the deployment of the algorithms within the cloud environment.
- The **Fusion & Presentation** element finally loads the results from the SAR and VIS processing and registers them to enable a combined presentation of the detected changes and anomalies. The outcome is provided to the Web Backend to finally forward it to the result presentation in the Web Frontend.

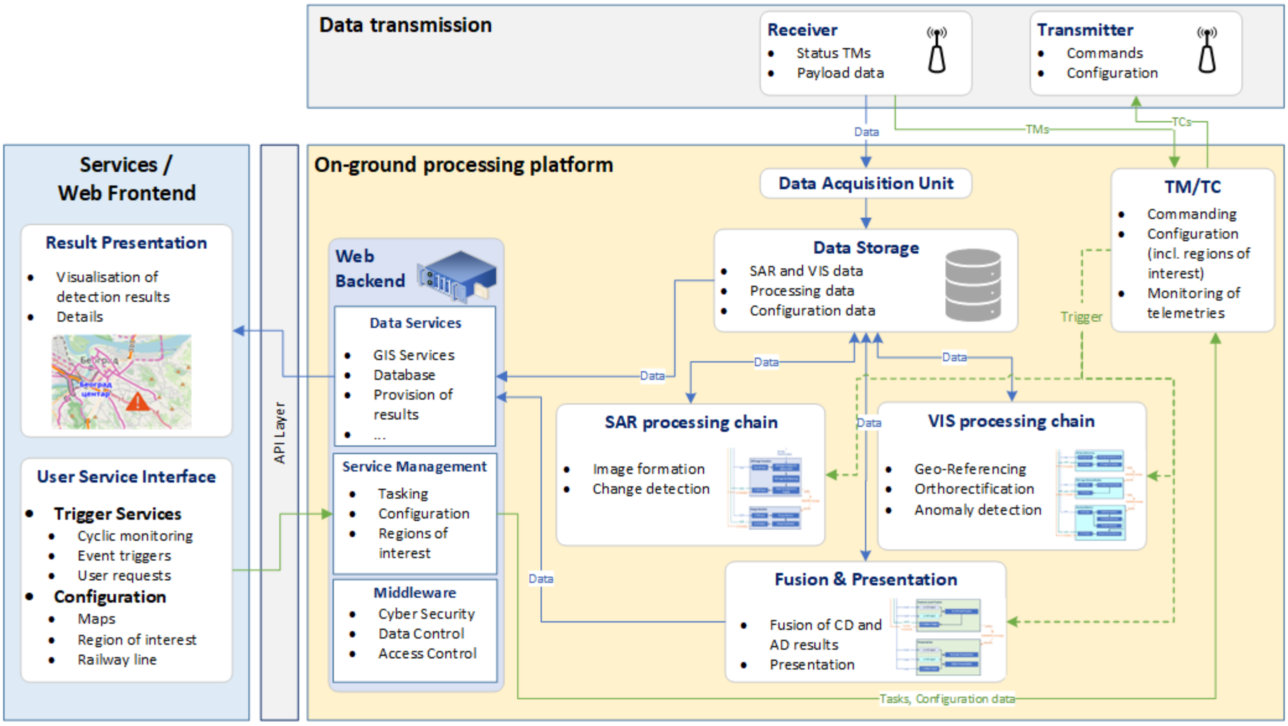


Figure 2-8: On-Ground Platform

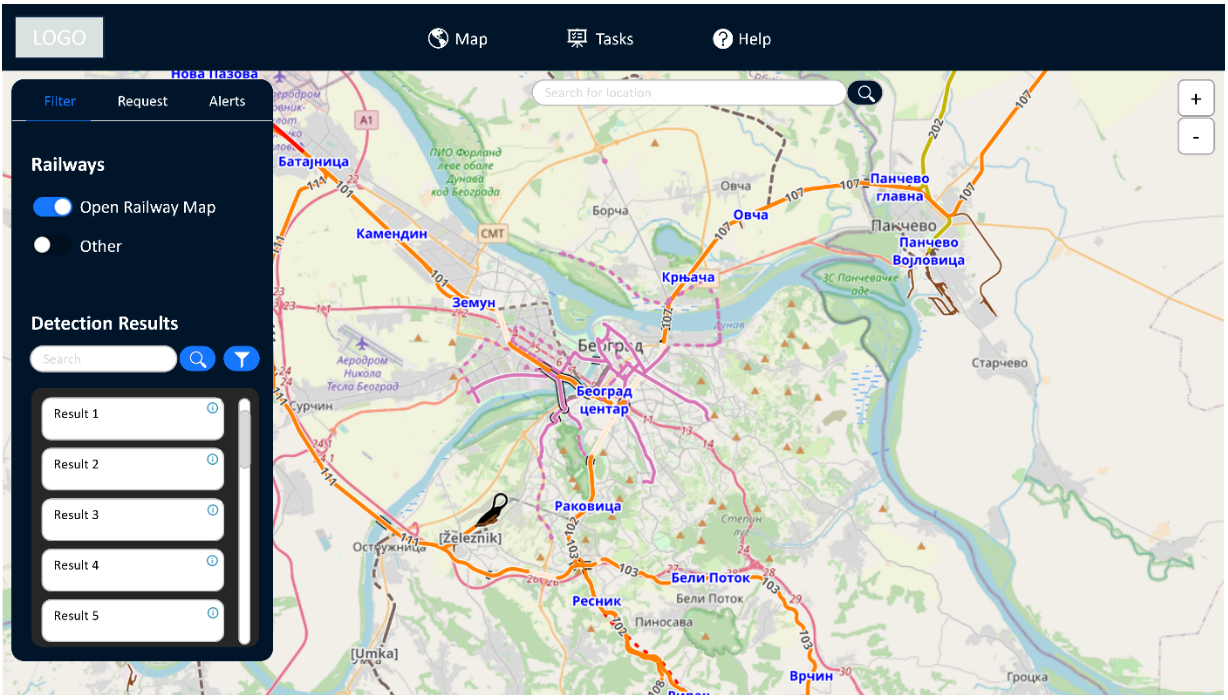
The **Data transmission** block in Figure 2-8 represents the technical infrastructure (transmitter and receiver) required to perform the communication between the on-board platform and the on-ground platform. The envisaged space system would require two different transmission paths for TCs/TMs and for the payload data: The transmission of TCs/TMs is usually done with frequencies up to 4 GHz (S band, see [10]), while the transmission of large payload data from satellite to ground requires higher frequencies, e.g. up to 40 GHz (K_a band, see [10]). Usually, the payload data is stored in a corresponding data storage unit on-board, until this unit is commanded to send all data to ground in a data stream (no PUS service). The reception and storage of such data streams require specific data acquisition units on-ground, while the TCs/TMs are processed by the TM/TC element, as already described earlier in this section. For the airborne demonstrator, a simplified set-up will be applied, using LTE for transmission of both, TCs/TMs and payload data.

The **Services/Web Frontend** block in Figure 2-8 represents the main user interface to the IIMEO system. In the IIMEO context, the term "service" refers to user-specific earth observation services, such as continuous monitoring or event-driven monitoring of infrastructures (like railway lines in this case). The usage of such a service is organised in so-called '**tasks**'. A task denotes a single action requested from the service, such as the monitoring of a railway line after a severe weather event. The Web Frontend provides the required functionality to run such tasks. In particular, it enables the user to perform the following activities:

1. **Configure and trigger a monitoring task:** The user can select a suitable map showing the infrastructures that shall be monitored (e.g. Open Railway Map [7] for railway tracks) and a region of interest or -alternatively- a specific part of the infrastructure, e.g. a dedicated railway line, that shall be analysed in particular. With these selections a monitoring task is defined that is started by the user afterwards. The task and its configuration data are then forwarded to the IIMEO system, which in turn processes the respective TCs and transmits the TCs to the next satellite of the envisaged IIMEO SmallSat constellation that crosses the selected region of interest.
2. **Viewing and analysing the monitoring task results:** Once the satellite has completed its monitoring task, it sends the results back to the on-ground platform, which makes them available to the user for further processing. The results are visualised in the Web Frontend by displaying detected disruptions at the corresponding position on the map with the option to show detailed information on demand, such as exact time and location, results of change detection and overlays of the acquired SAR and VIS data for the region of interest.

The potential use cases and the web frontend mock-ups were developed in close cooperation with the Serbian Railways (SRI), which will also act as the end user within the planned demonstration flight campaign in the final project year. This enables the incorporation of the user expertise into the design of the web front end.

Two different kinds of user interfaces have been identified as useful for the monitoring purposes: a website as the main user interface for the monitoring services, providing rich task configuration and operation functionalities and a mobile device application, featuring ad-hoc notifications about anomalies in the configured region of interest. Figure 2-9 shows the website mock-up, displaying the area of interest as a map and providing a configuration panel on the left side of the screen with the layout for map selection and representation of detection results.



● Open Railway Map

○ Other

Figure 2-9: IIMEO website mock-up

Figure 2-10 shows the mock-ups of the different configuration panel layouts. The left layout provides the option to select the applied map and the list of available detection results. The centre layout shows the option to select the railway line, either by start and end point or from a list. The right layout enables the user to select an alert event, from which the region of interest is derived that shall be monitored.

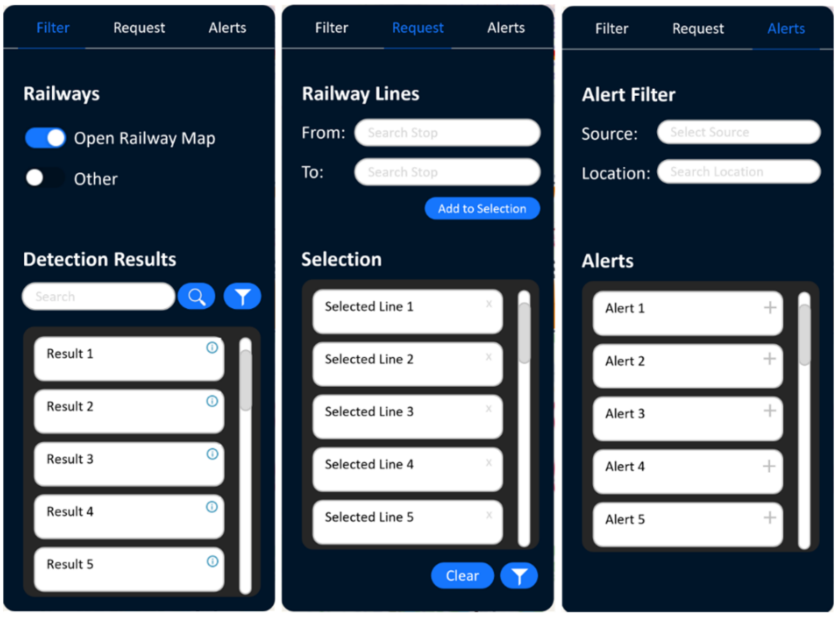


Figure 2-10: Configuration panel layouts

Mock-ups of the mobile application are shown subsequently: Figure 2-11 shows the mobile application's main screen. It provides everything what is needed to create a task, find an existing one, and also a layout of current, deleted, and recently viewed detections in the area of interest

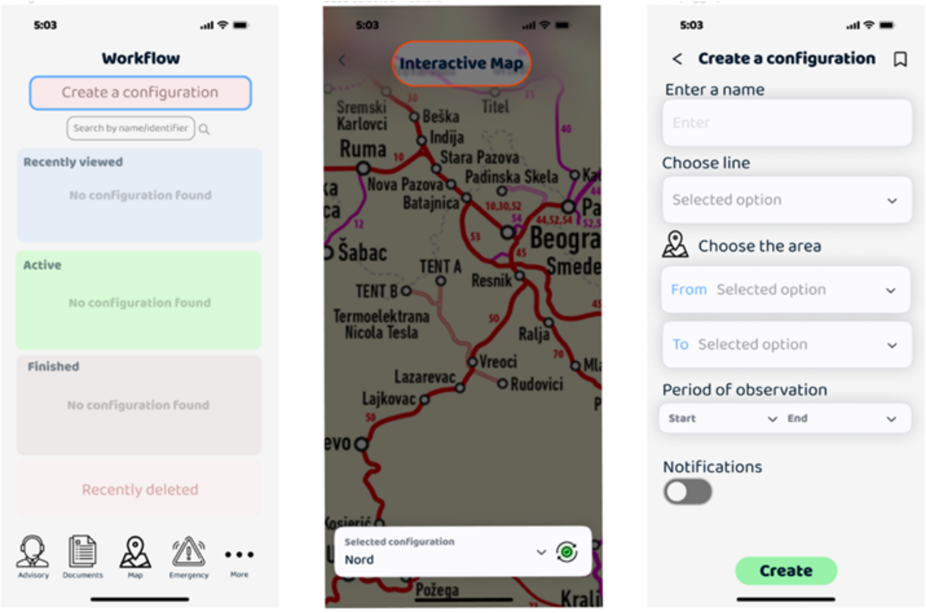
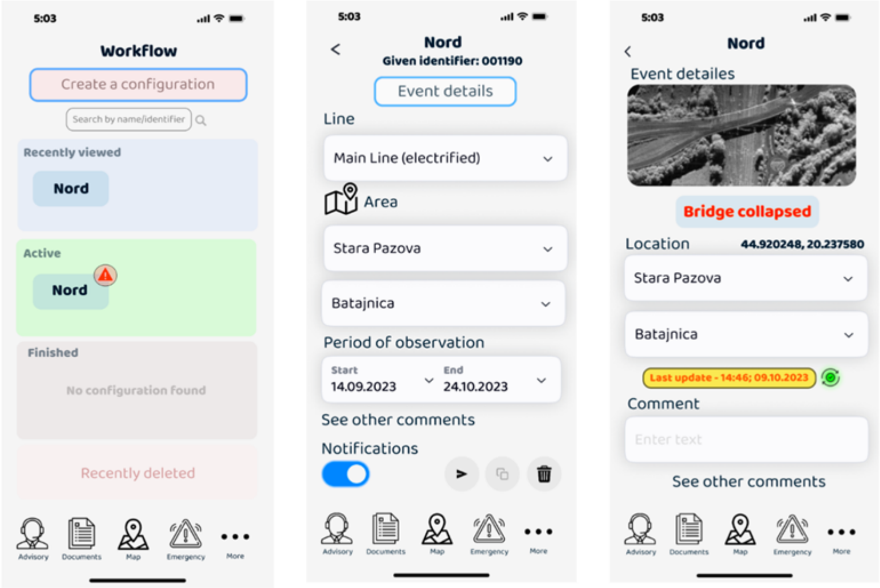


Figure 2-11: Mobile App - Main screen

Figure 2-12 shows the application's notification screen. After successfully creating a task, an updated layout of the main screen is shown (left). It is also indicated (small red warning triangle) that there is a notification for a new event. In the middle screen more details about the event are shown. Here we can change the data we entered earlier or just get additional information. The right screen shows the details of the event, namely the image itself (if available) and the exact location of the incident and time of the occurred event.



Line: Main Line (electrified)

Area: Stara Pazova, Batajnica

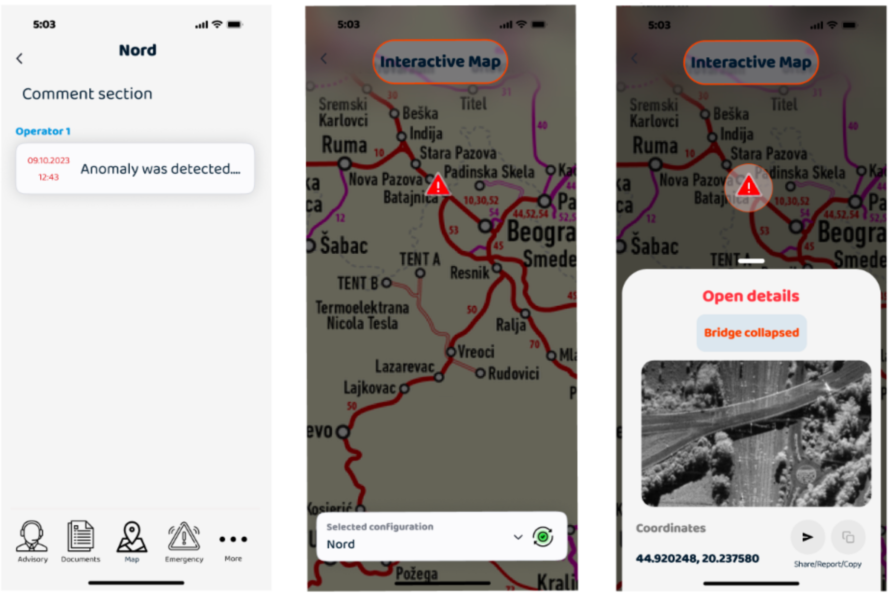
Period of observation: Start 14.09.2023, End 24.10.2023

Location 44.920248, 20.237580: Stara Pazova, Batajnica

Last update - 14:46; 09.10.2023

Figure 2-12: Mobile App - Notification

Figure 2-13 shows the application's screen for event details. After clicking on the location coordinates in Figure 2-12 (right), a map opens showing the exact location of the event (middle screen). We can see that there is an icon in our selected region, which indicates that an anomaly has been detected. The right screen in return provides a popup with brief information about the detected event.



Operator 1
09.10.2023 12:43 Anomaly was detected...

Selected configuration: Nord

Coordinates: 44.920248, 20.237580

Figure 2-13: Mobile App - Event details

3 APPLICATION SCENARIO

Reliable transport infrastructure is one of the backbones of a prosperous economy, providing access to markets, jobs, and social services. Two main means of transport over land are road and rail transport. It is generally acknowledged that railways are a comparatively safe mode of transport. Nonetheless, there are each year many recorded safety critical accidents caused by derailments and collisions between trains and obstacles on or adjacent to the railway tracks, so rail operations could be made even more safe if the number of collisions could be reduced. Besides the more frequent obstacles such as people trespassing the railway tracks, there are obstacles such maintenance equipment left on the rail tracks and stalled cars on the track. An example of the train accident caused by the maintenance equipment on the tracks is the fatal accident happened in Netherland on 4th[1].

Particularly hazardous railway obstacles are consequence of geological and natural hazards such as landslides, flooding and extreme weather conditions causing railway bridges damages/collapses and blocking the rail tracks due to fallen trees. Besides the derailments caused by train collision with obstacles on and near the rail tracks, often derailments are these caused by rail tracks deformations due to earthquakes or extreme heat. Hot weather can affect the rails, which can expand, bend, and even break in the heat, which are the effects known as "buckling rails" (see Figure 3-1 right side). In last decades, significant efforts have been put in development of trackside and on-board systems for autonomous detection of rail tracks and the obstacles on and near the rail tracks with the goal of both risk reduction to personnel, as no personnel walking along the line is required, and railway safety increase.

Figure 3-1: Different causes for defunction of railway infrastructure

Only a spaceborne approach is able to monitor infrastructure continuously and at large-scale. Other means such as airborne-based solutions can allow high-precision monitoring of small regions-of-interest, yet they become **too costly** when scaling up to larger areas. Furthermore, the airborne solutions are prone to environmental conditions that impede their usage in severe weather conditions, which are usually a trigger for railway infrastructure damages and occurrence of obstacles on the railroads that are envisioned to be detected by IIMEO technologies.

The IIMEO service prototype will be used in **relevant railway environment** to demonstrate and validate the overall end-to-end service as it could be operational in space, as well as the **near-real-time** service operation. IIMEO focusses with a resolution greater than 50cm on hazardous events/obstacles that are of static nature (i.e. in the time frame of one to few hours) and that could endanger the safety of the rail operation. Such static obstacles could cause direct train crash if the rail transport was not timely stopped (e.g. before the announced extreme weather conditions) or could cause significant delays in case of stopped rail transport to perform the inspection of the effected rail track. **Using of IIMEO services has potential to reduce delay and track down times, as well as to reduce the inspection effort/costs for track monitoring after occurrence of an extreme weather event.**

In this context, IIMEO pilot is mainly focusing on railway failures caused by extreme weather situations (e.g. landslide, flood, fallen trees etc.). A key reason for that is the increasing number of such weather events that, according to World Meteorological Organisation (WMO), has increased by a factor of five over the 50-year period, driven by climate change. This leads also to an increased downtime of the railway network. For

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[1] https://www.prorail.nl/nieuws/treinongeval-bij-voorschoten

example, research has shown that adverse weather conditions are responsible for 5 to 10 % of total failures and 60 % of delays on the railway infrastructure in Sweden. In addition, the current inspection measures of the railway track network after such events (e.g. by helicopter, drones, manual inspection) are very expensive and time consuming and in the case of severe damages due to weather-related events, together with restoring the damages and return to normal operations can last up to several days.

To conduct tests for the final demonstration as well as the demonstration itself, candidates for a flight site in Serbia have been selected which are managed by the project's pilot partner Serbian Railway Infrastructure (SRI). These test sites are characterised by the existence of a number of level crossings that could be included in demonstration scenarios as objects, possible obstacles, such as vehicles could be placed on them during the demonstrations. By this, the changes on the rail tracks caused by obstacles (objects that are on the rail tracks that do not belong to railway infrastructure), which are sufficiently large to be detected by IIMEO system, can be simulated during the field tests. Figure 3-2 shows an example of such track testing site within Serbia , that is part of the *Pan European corridor X* to Budapest in length of 244 km, which passes through Belgrade junction as a large urban centre and through the multiple towns along the route with multiple crossings and tunnels. Between town Markovac and Belgrade the track passes through hilly landscape with lots of sharp curves where the direct train view on an area behind a curve is blocked by vegetation or buildings along the route.

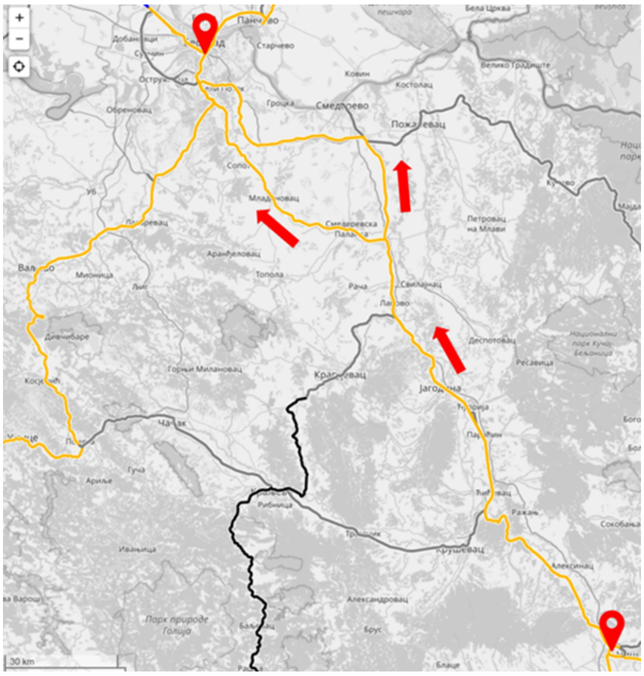

Figure 3-2: Potential railway testing site in Serbia

Final choice of the test sites for the field tests will be done based on their availability and permission to be issued by Serbian Railway Infrastructure. By this, it is taken into account that parts of the test sites may be under reconstructions/closed for regular traffic/low-exposed to traffic so that a number of different obstacles could be simulated. For examples, fallen trees or a vehicle will be placed on rail tracks at test site to simulate possible obstacles.

With such an airborne-based demonstration, SRI expects that a possibility/solution for a significant reduction of their current efforts (costs) and time needed for identification of railway failures caused by extreme weather situations will be demonstrated, showing the great business potential of the IIMEO solution. Reducing the time to one hour for the inspection of the spacious railway tracks will **significantly improve the operational railway availability and safe operation**. The envisaged demonstration will include the following activities:

- Acquisition of SAR and VIS data on-board of the airplane
- Real-time on-board processing and AI-based pre-selection of interesting regions containing hazardous events/obstacles with means of anomaly and change detection
- A real-time transmission of pre-selected data with already existing infrastructure
  Cloud-based service platform for off-board, high-resolution processing and visualisation of the results

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